Future Sources of Heavy Crude and their Production and Upgrading Technology

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ABSTRACT

Worldwide premium-quality lighter crude has been depleting during the last two decades. Future demands for petroleum is centered on the use of heavy and extra-heavy oil, which is difficult to produce, transport and refine. An assessment is made on the types and sources of heavy crude as feedstocks for the conventional upgrading technology, including the requirements for stringent environmental regulations. A strategy for future production (the up-stream) and upgrading (the down-stream) will be presented. Horizontal drilling, the use of microorganisms and a number of physical methods, such as ultrasound, median microwave, cold plasma, electrokinetic and monocrystalline intermetallics, etc., will be discussed for the first time.

INTRODUCTION

U.S. DOE[1] has assessed that for the world crude oil supply from 1900 to 2100, extra heavy crude and bitumen will be used as a significant portion of the total consumption (40 Mbbl/ day), near the year 2060. At present, engineers have developed a myriad of processes to convert fossil fuel residues to lighter liquids. For example, both thermal cracking and hydrotreating (hydrocracking) have been commercialized worldwide. Certain designs of a given process usually depend on the properties of the feed. In order to adopt a given unit for a variety of other feed streams, the particular process must be modified from the original tailor-made system developed and intended for a given source or type. Without exception, all existing and frequently used processes, e.g., the H-oil and LC fining, suffer from this shortcoming.

Typical heavy oils produced at different geographical locations are quite different in properties. In this analysis, the common heavy oil sources used by the traditional processes are listed. After most of these sources are depleted, other massive sources of heavy oil or bitumens will be explored for commercial uses. Also, future potential sources of extra-heavy oil and bitumens are evaluated. The current technology of the refining process is based on the following principles: carbon fragmentation, carbon rejection, hydrogen addition and carbon rearrangement.

In this manner, asphaltene becomes pivotal, for example, in the processes of deasphaltene, asphaltene cracking, asphaltic interconversion, hydrogenation, hydrogenolysis of the aromatics and heterocyclics[2]. Usually, the mass distribution of the four asphaltic fractions—asphaltene, resin, aromatics and saturates (SARA)—is the primary factor that determines the characteristics of a given heavy oil. For heavy oil or bitumens from tar sands, the asphaltic fractions (nonvolatile) are the major constituents. For naturally occurring asphalt and solid bitumens, the asphaltene content of both may reach 90%+. There is a vital need for an alternative, due to the present refining technology, and it is much preferred if this technology is mild (without the application of high temperature and pressure), to minimize pollutant formation, and is flexible in process design (modular, with no restriction of capacity). For the first time, a summary report of the new technologies, such as the chemical-assisted ultrasound and the nanotechnology-aided refining, has been evaluated.

ANALYSIS OF FUTURE SOURCES

Conventional heavy oil sources up to the present are as follows: bottom or residua from delayed coking or vacuum distillation (paving asphalt); fractions after hydrotreatment; native bitumens (native asphaltenes and native asphaltites); native asphaltoids (e.g., wuzterlite, ingramite, etc.); oil sand bitumens; pyrolized kerogen product mixed with bitumen (oil shale); residue field oil after thermal or fire flooding; mined green oil after well closure (after tertiary recovery process); coal derived liquid, either from stagewise pyrolysis or hydrogenation[3].

Due to the geochemical nature of oils from the same geological regions, oils that have been exposed to the same paleogeological environments should be similar. From these aspects, crudes from different sources are different in composition. Some of the massive reserves of heavy oils have been exploited for commercial use: the Venezuelan bitumen of the Orinoco basin and the heavy oil of Alberta and Saskachewan, for example, Cold Lake and Lloydminister; continental type of heavy oil from Liaohe and Karamay in China; residua of Maya and Isthumas from Mexico; and immature coastal deposits from California.

As the world turns around the corner of 2000, further potential resources become increasingly important, especially in many localities of the world, which can be extra heavy oil or bitumen: Eocene oil sand at Canbay basin in India; Volga-Urals' natural bitumens in Katakstan and Turkmenistan; Campos basin biodegraded oil in Brazil; Coastal bitumen type of Benin basin in Nigeria; Aswari limestone reservoir deposit in Iran; Duri field heavy oil in Sumatra of Indonesia; Zagros fold belt heavy oil in the Middle East; Narrows graben organic-rich oil shale in Queensland, Australia; Giant Green River oil shale in the U.S. For this study, the worldwide resources of coals, which can liquefy into liquids, are not included.

PRESENT TECHNOLOGY

At present, major, matured, commercial refining and upgrading processes can be summarized as: Foster Wheeler's delayed coking; Exxon's fluid coking and flexicoking (fluid coke gasified with air and steam); HRI-Cities Service's H-oil of ebullating-bed (now Texaco); Amoco's LC-Fining of demetallization and desulfurization (now Lummus Crest); Verba oil's VCC (Verba Combi Cracking) for liquid phase hydrogenation; and catalytic hydrofining; Shell's HYCON for HDM and HDS in series; Petro-Canada's CANMET using ferric sulfate as catalyst; Asahi-Chiyoda-Nippon Mining's SOC (super oil cracking) in slurry phase reactor; IFP-ELF-TOTAL's HYVAHL process.

Even for this short list, thermal cracking is still the major process. The success of a given process is dependent on the marketplace, but one can safely conclude that the combination of more than one is of advantage. A simple example is the combination of thermal cracking and hydrotreatment. Three different modes of hydrocracking are mentioned, which are fixed bed, ebullating bed and moving bed. The addition of a fixed-bed hydrotreater to the existing hydrocracking unit is very effective for the high-quality liquid. In this way often an integrated multi-stage unit is superior when compared to a single-stage unit.

HORIZONTAL DRILLING

Horizontal well steam stimulation has been adopted by a number of companies for pilot tests. For the thermal recovery of heavy oil, the conventional steam stimulation (CSS) and single-well steam circulation (CWSC) for drilling the horizontal length can reach one mile (usually somewhat below 2600 feet in order to avoid drainage of the existing vertical wells). Therein, extension and enlargement of zones can be used for chemicals, physical methods, instruments and microorganisms equally well. If completion work is done in a horizontal well, the layers in the horizontal well serve as both spaces and as individual reactors for further conversion of the oil.

CHEMICAL ASSISTED ULTRASOUND

Since asphaltene and related asphaltics (resin, gas oil, etc. the non-volatiles in petroleum, etc.) in residual oil are very complex in their intermolecular forces among individual species, such as association, assemblage, aggregation, interaction, etc., thermal energy by high temperature heating is not selective and may result in damage. For example, good (premiere) molecules may undergo polymerization and become coke. The effects caused by ultrasound can be attributed to three phenomena. First, there is a rapid movement of fluids caused by a variation of sonic pressure, which subjects the solvent to compression and rarefaction. The second phenomenon, and by far the most important, is cavitation. It is generally accepted that the formation and collapse of microbubbles is responsible for most of the significant chemical effects that are observed. The instantaneous pressure at the center of a collapsing bubble has been estimated from theoretical considerations to be about 75,000 psi. The temperature has been similarly estimated to reach values as high as 5200K. Actually, this technique can be operated at one atmosphere and room temperature. This process is called cold cracking. This violent implosion of the microbubbles also gives rise to luminescence. Thirdly, there is microstreaming, where a large amount of vibrational energy is put into small volumes with little heating. The application of ultrasound frequency for radiation can maintain the range from 25 to 40 kHz at an energy density of 20-600 W/cm^2. Under the cavitation conditions, two events may occur simultaneously, thermal scission of bonds of heavy oil according to Rice mechanism of cracking, and the generation of hydrogen atoms. These are essential for the upgrading of heavy molecules in residual oil and other residua. Fossil fuels, so far, that have been studied include Athabascar tar sand, Kentucky tar sand, paving asphalt, Monterey crude, coal liquids, Stuart and Maoming oil shales and the improvement of the quality of reducing the asphaltene content has been found. Furthermore, the ultrasound can be applied in situ for generations of oil by reduction of viscosity using a drilling wanted with a number of transducers.

COLD PLASMA

The often-used control technology for hydrogen sulfide is the Claus method and the process stream after hydrodesulfurization from reformer, which has to purify this sour gas through Claus/SCOT unit. All these will lose the value of hydrogen since both processes require oxidation. The microwave method of utilizing the plasma dissociation process has also been developed. The plasma dissociation will save 0.24×10^{12} BTU/y for every 156 ton/d of Claus/SCOT plant.[5]

INTERMETALLIC FILTERS

Most recently, an intermetallic filter specifically for the removal of sulfur and improvement of the quality of feed has been in development.[6] The surface of Sn-Sb intermetallic has been shown to react with the sulfur species through the adsorption destruction by nanoscale technology. The preliminary results are very encouraging for high sulfur-containing crude oil; in general, a few pass through a fixed bed; the sulfur content has decreased by 50% and the asphaltene has also been reduced by 20%. As indicated in standard textbooks,[7] a filter can be a biofilter where the microorganisms are applied or an electrokinetic filter (potential difference, applied or induced), where the intermetallics are used. The device is very versatile, which can be attached or connected to any configurations in series or in parallel.

MICROBIAL ENHANCED OIL RECOVERY (MEOR)

Contrary to the Public's understanding, the MEOR method is more efficient for the recovery of heavy oil rather than light oil.[8] In a horizontally-drilled well, microorganisms can be introduced at certain levels of the pay zone. Very recently, one case has been found that all the recovery methods failed; MEOR is the only successful one.[9] The advantage of using special thermophilics for fermentation at the bottom of the hole has been described for the future ultimate oil recovery (UOR), as described earlier.[10]

CONCLUSION

A challenge is made to produce, transport, and refine the extraordinary crude and bitumens. A recommendation is therefore made for the future of the refining and upgrading industry for applying different, newly developed devices to enhance their efforts.

The use of a successive, multi-step unit (including the pre- and post-treatment unit to the maintrain) is to selectively eliminate the small amounts of bad molecules (molecules containing S, N, X and M), by targeting the destructive power on bad molecules, using a specific frequency of the irradiation (e.g., ultrasound, microwave, cold plasma, electrokinetic, induced field, magnetic force). Conventional refining technology, based on the premise that both good (major) molecules, and bad (minor) molecules, are treated with much excessive power in order to crack the very small amount of bad molecules, is not energy-saving. To achieve success in future refining and upgrading of heavy oil, research should not be centered on catalysts and reactor design alone, but also on the overall interdisciplinary knowledge of the nature of asphaltene pertaining to the geochemical transformation and formation. The recent concept,[11] that asphaltene and its related substances are continuous in transformation, is of paramount importance for the conversion.

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